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A SUMMARY OF THE LITERATURE ON MILKWEEDS (ASCLEPIAS SPP.) AND THEIR UTILIZATION

Compiled by
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Compiled by A. GERALDINE WHITING, *assistant librarian, (assistant in the Division of Bibliography), Library, United States Department of Agriculture*

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INTRODUCTION

Milkweed fiber was used in prehistoric times in North America and in Africa—the two areas where many species of *Asclepias* are indigenous (*11*, *48*). It has also a long and varied history of experimentation for more modern use. At present, interest is renewed because the floss of the common milkweed (*Asclepias syriaca*) is our only native fiber similar to kapok (*9*). It is a possible substitute for the kapok or cork used in life preservers, as Berkman stated in testimony before the Committee on Agriculture of the House of Representatives (*9*).

The literature on *Asclepias* stresses its use for fiber production and rubber production. Experimentation on fiber production has been

[1] This summary is based entirely on the studies which are cited in the bibliography and to which reference is made by number. Abstracts have been used where titles have not been readily available, and these are indicated in the citations. Patent literature has not been searched.

Grateful acknowledgment is made to those who have given help both in the search for references and in criticism of the text.

chiefly with *A. syriaca* L. (*A. cornuti* Decne.), less with *A. incarnata*, and a little with other species. Investigation for rubber production has been most extensive with *A. syriaca*, but work has also been done on *A. subulata* and *A. erosa* and, to a limited extent, on several other species. Recent study of the plant includes not only fibers and rubber but other products such as paper, cellulose, and oil.

FIBER PRODUCTION

HISTORY

Milkweed yields two kinds of fiber, the bast fiber of the stem and the floss, or seed hairs.

Whitford (*48*) described the use of the bast fiber of four species by the American Indians, with *Asclepias syriaca* most widely used. Natives of Tanganyika also use the stem fibers of *A. semilunata* for fishnets, as Braun reported (*11*). Rheineck (*40*) stated that it is not known whether the American colonists used *A. syriaca* before it was used in Europe.

A. syriaca, the species recorded earliest in the literature, is of American origin. Neish (*37*) noted that it is widely spread in eastern United States and southern Canada. It was early taken to Europe, probably as an ornamental (*35*). Kuz'menko (*33*) said that it was widely distributed in Germany and France, where it was grown as a garden plant or for its fiber, and that it reached Russia near the end of the eighteenth century. Eventually the plant escaped and became naturalized (*33*, *35*).

The first use of the fiber was made, according to Kuz'menko (*33*), by Gleditsch, in Germany, between 1746 and 1748. He used the floss for padding. At the same time La Rouvière in France produced cloth from the floss (*35*). Lichtenstein (*34*) reported that there had also been attempts in Germany—described by Schnieber in 1789 and by Friese in 1791—to produce fiber.

In America, Cutler (*13*), writing in 1785, reported that the floss made an excellent wick yarn for candles. Genet (*19*), in 1814, said that no use was made of it in New York State, although milkweed was very abundant, but that in France it was used for making cloth and velvets more lustrous than silk and taking dyes well.

In 1838 the shortcomings of milkweed were summarized by Lichtenstein as follows: The seed was not adapted to cultivation, and the floss was weak and brittle as a spinning fiber, did not take dyes well, and became lumpy when used for padding.

About 1860 interest in milkweed revived in Germany and Russia. In Germany, Meitzen (*35*) in 1862, after extensive experimental studies based on a careful survey of the earlier work, reported unfavorably on the fibers of the plant. In Russia, according to Kuz'menko (*33*), an attempt was made in 1867 to organize a society for the distribution and cultivation of milkweed.

In America, meanwhile, several ventures in the cultivation of *Asclepias incarnata* and *A. syriaca* in Canada were reported by Kirkwood in 1867 (*31*). Dodge (*15*, *16*) in 1894 and 1897 included several species of *Asclepias* in his surveys of fiber plants. He described experiments in Minnesota with *A. incarnata*, but said that *A. syriaca*

had not been tried in America and that elsewhere experimentation had been limited. At this time also Sydney Smith Boyce (*2, 3, 4, 10*) was working to produce from the bast fiber of *A. incarnata* a fine-art textile—"ozone fiber"—which would be cheaper than cotton or silk and would combine the best qualities of both. Later American work is recorded in Neish (*37*), Merrill (*36*), Neish and Burns (*38*), and Schorger (*41*).

At the Iowa Agricultural Experiment Station between 1925 and 1929 *Asclepias syriaca* was grown on a nearly commercial scale in order to test actual growing conditions and possible utilization. The results are given in the annual reports of the station (*29*) and are summarized by Gerhardt (*20*).

In Germany, during the first World War, Schüroff (*42*) came to the conclusion that *A. syriaca* was unsuitable as a domestic source of fiber. In 1918 Ulbrich (*44*) mentioned the floss as a possible substitute for kapok in upholstery. Dischendorfer's work, reported in 1926 (*14*), reexamined that of Meitzen and reaffirmed his unfavorable conclusions.

In England, a so-called new fiber, "artificial cotton," was announced in 1928 by the English Artificial Cotton Production and Marketing Corporation. Hedley-Thornton (*27*), chairman of the corporation, said that he had worked with an artificial cotton plant grown from roots and with an *Asclepias* fiber grown from seed. He claimed that he had developed by a secret chemical process a fiber which, when mixed with cotton, silk, rayon, or wool, could be spun by existing machinery with slight adjustments. Bruno (*12*) found that the plant was *A. incarnata*. Goulding (*21*) also thought it was *A. incarnata*, and added that the company had gone out of existence after a year or two without producing fiber commercially.

In 1938 another new fiber, "cotine," was announced (*5*). It had been grown experimentally on the Continent and an English company formed to develop it. Nerling (*39*) and Ulbricht (*45*) examined this fiber and identified it as *A. syriaca*.

The Imperial Institute of Great Britain between 1905 and 1931 made a series of technical tests of the fibers of several African species (*22, 23, 24, 25, 26*). Kondratsky (*32*) in 1928 and Kuz'menko (*33*) in 1929 stated that the Russians, in their examination of Russia's potential resources, studied *A. syriaca*, which is widely distributed in the Ukraine. Likewise, Fischer, in Germany (*17*) in 1941, reported his investigations of *A. incarnata*. More recently, interest has been active in the United States (*9, 28, 43*) and in Russia (*51*).

ASCLEPIAS SYRIACA (COMMON MILKWEED OR SILKWEED)

Asclepias syriaca has been described by Hall and Long (*57*) as a stout perennial herb with characteristic milky sap, or latex. Its roots probably spread by deep horizontal branches. Its stems, 3 to 7 feet tall, are erect and simple to the flower clusters and are often crowded to form extensive thickets. The leaves are opposite, with 20 or more to a stem. The numerous flowers, dull purple to white, are in umbels. Flowering is from late June to September, and the fruit pods mature late in August and September. The pod has many seeds, each with a tuft of silky hairs or floss (*35*).

Botanical Characteristics of the Floss.—In 1862 Meitzen (*35*) gave the first account of experiments with the industrial possibilities of the floss. He found that each seed hair is single-celled, smooth, thin-walled, and brittle and that it does not have a twist like that of cotton. Neish and Burns (*38*) found the seed hair 30 to 43 mm. long; resilient, but at the same time brittle. In cross section it is oval or circular, with irregularly pitted walls and the inner canal or lumen partly filled with dried protoplasm.

Dischendorfer (*14*) found an average of 910 hairs to a seed. Berkman reports 75,000 hairs to a pod. According to Dischendorfer, the average weight of a tuft is approximately 2.7 mg. and of a single hair 0.00277 mg., about half the weight of most cotton fibers. He thought that the single fibers were long enough for spinning, since they averaged 33 mm. and some measured 39 mm. The tip is very brittle, however, and easily lost in handling, so that the length is reduced to 29 to 25 mm. or less. The hair tapers in diameter from 31μ to 33μ at the base to 5μ to 7μ near the tip.

Dischendorfer's examination of the structure of the fiber showed that its wall, covered with a thin cuticle, is about 1.5μ thick. Its thickness shows great variation—0.8μ toward the tip to 10.0μ near the base—on account of its network of pitting and ridges. These are especially marked toward the tip, which is rough and granular, whereas the rest of the fiber is smooth and glossy. He concluded that the brittleness of the tip was due in part to these thin or perforated areas in the wall. The lumen forms 77 percent of the diameter in the lower portions of the hair and 60 to 64 percent in the upper portions. It is filled with air except for traces of dried protoplasm.

Berkman (*8,9*) found the fiber of *A. syriaca* very like kapok. Both fibers have a wide air cell and very thin walls. They are similar in diameter and nearly so in length. Both have a silky, lustrous appearance and are light and soft; both fill confined spaces without packing because of their elastic springiness. Furthermore, they are water-resistant because of the waxy coating of their fibers.

Chemical and Physical Properties of the Floss.—The ash of milkweed floss contains iron, alumina, calcium, potassium, sodium, and magnesium, combined with silicic and phosphoric acids (Meitzen, *35*). Neish and Burns (*38*) report that the ash content varies from 0.9 to 1.48 percent, of which 0.2 percent is phosphate. They found also calcium and traces of chlorides. Dischendorfer (*14*) concluded that the ash content contributed to the brittleness of the hair, especially at the tip, because he found 4.48 percent in the tip, 3.71 in the middle portion, and 2.03 in the base, with the average for the whole hair 2.44 percent. Rheineck (*40*) also analyzed the percentage of ash. He tabulated the reports of the ash content found by four investigators as follows:

	Percent
Meitzen	1.86
Schorger	.97
Dischendorfer	2.44
Rheineck	.76
(Neish and Burns	.90–1.48 [not included by Rheineck])

Rheineck explains the difference in results on the basis of geography, noting that he and Schorger used Wisconsin milkweed and their figures were similar. Berkman states that the ash content is nearly identical with that of kapok.

Schorger (*41*) gives the composition of the floss as follows:

	Percent
Lignin	22.18
Pentosans	34.55
Methylpentosans	1.05
Methoxyl	3.60
Cellulose	60.40
Alpha-cellulose in cellulose	58.64
Soluble in alcohol	4.28
Soluble in ether	1.35
Ash	.97

Neish and Burns (*38*) stated that the lignin content of the hair is greater than that of cellulose. Votoček and Zvoníček (*46*) examined the floss to determine the presence of true cellulose or hemicellulose. They reported hemicellulose basically of xylose—a xylan; and cellulose basically of glucose—a true cellulose.

Gerhardt (*20*) compared the composition of milkweed floss with that of other fibers, as shown in table 1.

TABLE 1.—*Composition of various plant fibers (moisture-free basis)* [1]

Fiber	Alpha-cellulose	Lignin	Furfural	Loss by acid hydrolysis	Furfural in cellulose
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Cotton	90.51	0.35	0.80	2.79	----------
Milkweed stem	36.68	12.56	13.42	32.75	5.20
Milkweed floss	34.86	12.69	19.07	33.00	5.36
Kapok	35.12	8.14	15.05	33.80	7.54
Corn stover	30.26	9.50	14.78	41.50	4.55

[1] Data from Gerhardt (*20*), published in 1930.

He pointed out that there is little difference in composition between the floss of milkweed and kapok. In their high lignin and furfural content they are more like hardwoods than they are like cotton. His tests of the fiber strength of milkweed showed a breaking strength of 4.2 gm. and a tensile strength of 30.0 kg. per mm.^{2} The breaking strength of cotton, he reported, was 7 gm. and its tensile strength 34.27 kg. per mm.^{2}

The percentages of cellulose and lignin found in the seed hairs as summarized by Rheineck (*40*) are shown in tables 2 and 3.

TABLE 2.—*Percentages of cellulose and alpha-cellulose in the seed hairs of Asclepias syriaca as determined by 3 investigators* [1]

Cellulose and alpha-cellulose	Schorger	Gerhardt	Rheineck
Cellulose	60.40	----------	55.00
Alpha-cellulose in cellulose	58.64	----------	65.25
Alpha-cellulose in seed hairs	35.40	34.86	35.90

[1] Data from Rheineck (*40*), published in 1939.

TABLE 3.—*Percentage of lignin in the seed hairs of Asclepias syriaca as determined by 3 investigators using different methods*[1]

Method	Schorger	Gerhardt	Rheineck
	Percent	*Percent*	*Percent*
72 percent H_2SO_4	22.18		20.35
42 percent HCl			21.16
44 percent NaOH at 100° C. at 10 atmospheres		12.69	

[1] Data from Rheineck (*40*), published in 1939.

Rheineck established also the presence of a sterol, a hydrocarbon, uronic acids, and a glucoside.

In examining the physical properties of the floss, or "coma" as they called it, Neish and Burns (*38*) established its low conduction of heat and its buoyancy in water. To test heat conduction they brought certain substances to the boiling point in beakers and completely insulated them with milkweed floss. The rate of loss of heat was measured by readings taken during a period of a half hour. Comparisons with analogous data for other insulating materials—cotton, wool, kieselguhr, and magnesia—indicated that milkweed floss is a very poor conductor of heat. Berkman (*9*), pointing out the importance of the air spaces within and around its fibers, found milkweed more resistant to heat transmission than any other material he examined. His figures of the conductivity index are shown in the following tabulation:

Milkweed floss	0.207 to 0.24
Kapok	.24 to .25
Wool (considered the warmest material)	.26
Fur	.28
Cotton (a solid fiber)	.39

Milkweed floss, because of its slight oil content (Neish and Burns, *38*) and its waxy coating (Berkman, *8*), is somewhat water-resistant. Neish and Burns suggest that this quality, together with its lightness, makes it suitable for use in life preservers. Tests were made with canvas bags filled with floss and weighted with lead so that they would just float. The resulting data show that milkweed does not support as great a weight per weight of floss as kapok supports but that it retains its buoyancy longer (*38*). (See table 4.)

TABLE 4.—*Length of time various weights of milkweed sustained various weights in water*[1]

Floss	Weight of bag	Weight of milkweed	Weight of lead	Time before sinking
	Grams	*Grams*	*Grams*	*Hours*
Bag No. 270	18	14	235	52
Bag No. 220	18	23	275	50
Bag No. 285	18	23	165	40

[1] Data from Neish and Burns (*38*), published in 1921.

Gerhardt's comparison of the buoyancy of milkweed with that of other fibers also shows little difference between kapok and milkweed. (See table 5.)

TABLE 5.—*Length of time 10-gm. samples of milkweed floss, kapok, and cotton sustained various weights; ratios of weights suspended to weights of fibers* [1]

Fiber (each sample 10 gm.)	Weight suspended	Time suspended	Ratio of weight suspended to weight of fiber	Weight added to induce submersion
	Grams	*Hours*	*Ratio, 1:*	*Grams*
Milkweed floss	590	0	59	0
	370	116	37	20
	300	168	30	100
	260	168	26	190
Kapok	600	0	60	0
	370	116	37	25
	300	168	30	108
	260	168	26	198
Cotton	290	0	29	0

[1] Data from Gerhardt (*20*), published in 1930.

Berkman (*9*) said in his testimony that milkweed floss has the same buoyancy as kapok and that this statement is supported by tests made in the laboratory of the Philadelphia Navy Yard. He gave the following figures showing the weight sustained for more than 48 hours by 1-pound samples of milkweed floss:

Sample 1	54 lb. 9 oz.
Sample 2	46 lb. 2 oz.
Sample 3	49 lb. 5 oz.

He concluded that on an average 1 pound of floss sustained a weight of 50 pounds for more than 48 hours and 3½ pounds of floss would keep a man afloat for more than 72 hours.

Neish and Burns (*38*) tested the resistance of milkweed floss to deterioration and molds. They subjected the floss to soaking, slow drying, and exposure to molds every week for 3 months and found that the loss of buoyancy was only 8 percent, that there was no appreciable loss in weight, and that the floss was only slightly discolored. Berkman (*9*) detected no deterioration in storage, since floss collected in 1938 showed no differences from floss collected in 1941.

BOTANICAL CHARACTERISTICS OF THE BAST FIBER.—According to Meitzen (*35*), there is little reference to the bast fiber of milkweed before his work in 1862. In a general study of the anatomy of the stem, he described the fiber cells as occurring in a row of bundles in the bast layer, outside the cambium and woody tissues. In older stems there may be two rows. The bundles are surrounded by parenchyma and associated latex vessels. In cross section they are usually circular but sometimes irregular. Each bundle contains from 40 to 50 fiber cells. The fiber cell is elongated and cylindrical. Nerling (*39*) described it as round-oval to flat-oval in cross section and pointed at the ends. Kondratsky (*32*) gave the length as 40 to 50 mm. or even 100 mm. and the diameter as 14 to 15μ, tapering to 2 to 1μ at the points. Measurements of length given by Nerling were 15 to 50 mm. and of diameter 0.012 to 0.030 mm.; according to Gerhardt (*20*) the cells are 15 to 25 mm. long and 0.25 to 0.50 mm. in diameter

According to Meitzen (*35*), the lumen is larger and the secondary and tertiary thickenings of the wall are less clearly marked than in flax or hemp, which are much stronger. He described the walls as

lightly marked with parallel lines, not pitted. Kondratsky (*32*) reported a network pattern.

Ulbricht (*45*) restudied the bast fibers in the light of Meitzen's work. He also reported two rows of bundles, the inner series noticeably smaller. He found them irregular in outline, a characteristic which he considered would be useful in tests to distinguish this fiber from others. The bundles are weakly joined to the surrounding parenchyma but in old stems seem to have torn from this and to lie free in the surrounding tissue. He found 15 cells across the diameter and 85 cells in the bundle, as compared with 50 found by Meitzen. This cell count, he says, is very much greater than that of hemp or flax. He states that the fibers have a narrow lumen and thick, unlignified walls with fine lamellae.

Chemical and Physical Properties of the Bast Fiber.—The chemical composition of the bast fiber has had little attention in the literature. Meitzen (*35*) reported the ash content to be similar to that of the floss; Gerhardt (*20*) reported it as 0.3 percent. Berkman (*9*) found a 92 percent alpha-cellulose content, and compared it with cotton, which has 94 percent alpha-cellulose. Meitzen found the same brittleness in the bast fiber as in the seed hair—both for the single cell and the whole bundle. This characteristic he accounted for in the chemical composition of the cell. The fiber is similar to flax and hemp, especially hemp. It is nearly as strong as these but not as durable, since the brittle fiber gives way under sudden stress (*35*). Dodge (*15*), on the other hand, thought that the only part of the plant practicable for use was the bast, which produces a fine, long, glossy fiber, strong and durable, ranking in quality between flax and hemp. Neish (*37*) concurred in the opinion of Dodge and added that, by carefully regulated processing, fibers the length of the stem could be obtained. Nerling (*39*) discussed especially the single fiber cell, pointing out that the bast fiber readily lends itself to cottonization. Tests of the single cell showed that its tensile strength and extension were high. Gerhardt (*20*) compared the breaking and tensile strengths of the bast fiber with those of other fibers, as shown in table 6.

Table 6.—*The breaking strength and tensile strength of milkweed bast fiber as compared with certain other fibers*[1]

Fiber	Breaking strength	Tensile strength
	Gm.	*Kg. per mm.*[2]
Milkweed bast	20	40.80
Cotton	7	34.27
Linen	16	36.40
Artificial silk	10	37.00
Manila hemp	31	52.00

[1] Data from Gerhardt (*20*), published in 1930.

Culture.—The cultivation of *A. syriaca* was first described by Meitzen (*35*) in 1862. He experimented with propagation by seed and by the perennial root. The seeds were planted in a seedbed; transplanted to a second area where the young plants would be protected in the winter; and, in the second year, transplanted to the field, the plants

2 to 3 feet apart in rows 3 feet apart. In propagation by root, however, the root pieces were planted directly in the field.

Gerhardt (*56*), in studying vegetative propagation, found that numerous adventitious buds appear on the roots. From these, plants may be started with little loss of time provided the root pieces are cut from roots that have remained out all winter. This he found important because the root appears to have a winter rest period. Experiments with propagation by seed, described in the annual reports of the Iowa Agricultural Experiment Station (*29*) and by Gerhardt, showed that there was a long after-ripening period and that there was poor germination unless the hard seed coat was broken. This was done by scarification shortly before spring planting and resulted in 95-percent germination.

The soil requirements of milkweed have been reported by several investigators. Meitzen (*35*) found that it thrives in dry sandy soil and not in wet heavy soil. Neish (*37*) reported that it grows abundantly in Canada and the United States on all types of dry sandy or clay soils. That it can be grown on soil unsuited to other crops he considered a factor advantageous in economic competition with other established and more profitable crops. Hall and Long (*57*) noted this point also, but questioned whether extensive areas of such soil would be available. Kondratsky (*32*) suggested such places as railroad embankments. This possibility of culture on unused areas is emphasized by Kuz'menko (*33*), who observed the plant in the Ukraine, where it has become naturalized and has, he thought, developed a locally adapted strain.

Neish and Burns (*38*) observed a marked influence of the condition of the soil on the quality of the fiber. Limestone soil produced a white bast fiber which was strong but brittle. Sandy soil produced a flexible, weak fiber, and clay soil an equally poor fiber. In a wet climate or season the bast fiber was brittle and weak—nearly useless; the floss was darker in color and lower in buoyancy and resistance to decay. Ulbricht (*45*) stated that a fair to good soil and, for the best development of the fiber, a rich fertilizing are necessary. An article in 1942 on Russian experiments (*51*) observed that a moist, fertile soil and adequate rainfall are essential because, although the mature plants withstand long spells of dry weather, young plants do not. This article noted in addition the need for regular care and suitable fertilizer. Berkman (*9*) also recommended fertilizer and a cover crop as well, such as a perennial grass.

Flowering in the second or third year of plants grown from seed is reported by Meitzen (*35*) in Germany. The experimental plot at the Iowa station (*29*) produced plants during the first year 12 to 24 inches in size, many of which bore fruit the same year. As a crop, however, it failed to mature in the first year from seed (Gerhardt, *20*). Kondratsky (*32*) reported that the plant matured fully in one year when it was grown from root pieces. Berkman (*9*) emphasized its perennial nature, in that it grows from the same roots for 7 years without reseeding. In 1942 Russian observations (*51*) placed this figure at 10 to 15 years.

Meitzen (*35*) made a clear distinction between the cultivation of plants for floss and for bast fiber. In the production of floss the plants were maintained in rows, and between the rows the soil was

cultivated in order to eliminate suckers from the spreading roots. The rows were thinned to ensure sturdy stems and fully developed pods. In the production of bast fiber, the plant areas were uncultivated and the plants allowed to develop as many stems as possible. Meitzen believed that overcrowding produced a more uniform growth of taller plants with less woody and thus more pliable fiber. At the Iowa station, where the crop was harvested for both floss and bast fiber, the plants were severely thinned to prevent this overcrowding, as it was considered a factor in reducing the total yield (*20*). Ulbricht (*45*), in discussing experiments in cultivation of bast during the first World War, stated that crowding tends to suppress growth but that too wide spacing permits undesirable branching.

Harvesting and Processing of the Floss.—*Asclepias syriaca* flowers from June to August, according to Meitzen (*35*); hence the fruit ripens irregularly. In September and October it is ready for harvesting. The pods must be gathered by hand and at the right moment so that none of the crop will be lost or its quality spoiled by weather. Neish and Burns (*38*) found that for the best quality it was necessary to pick the pods before they were fully ripe and to allow them to dry slowly and evenly in a warm dry place. They removed the light seed with its floss from the heavier pod by an air blast. Seed and floss were separated by a machine similar to that used for kapok.

At the Iowa station also the pods were gathered before opening. At first a cotton gin, with some modifications, was used, but with unsatisfactory results; the second year the seed and floss were separated by hand. Berkman (*9*) likewise thought it necessary to gather the pod by hand at the right period before opening. He considered that all the pods could be gathered at one harvesting, as a certain amount of ripening takes place after picking. For this the green pods are placed in onion bags and hung in circulating air. For the first 2 or 3 weeks these must be turned every 2 days to prevent mold, but after this predrying they will keep for a number of years. For further processing, the pods must be dried so that they will open of themselves. Berkman dried them under a great expanse of gas burners (Stouffer, *43*). The pods open inside out and are run through a "milkweed gin," one of Berkman's patents.

The calculated yield of an acre of milkweed, as given for the first harvest at the Iowa station (*29*), was 12.5 bushels of seed, weighing 20 to 25 pounds per bushel, and 100 pounds of floss (Gerhardt (*20*) gives 120 pounds). This was considered a fourth of the potential yield, owing to overcrowding. In the second year the harvest was at the rate of 30 bushels of seed and 280 pounds of floss per acre. Gerhardt calculated a maximum yield per acre of 48 bushels of seed and 480 pounds of floss in 576 bushels of pods, on the basis of one plant with 10 pods per square foot, yielding 10 gm. of seed and 5 gm. of floss. Kondratsky (*32*) briefly reported a yield of 30 to 40 pood (1 pood=36.1 pounds) per dessiatine (2.7 acres). Berkman (*9*) gave the yield of floss, collected in 1941 from 5 acres of good stands of wild growth, as 2,000 pounds of dry pods—that is 400 pounds per acre—and, counting the floss as one fourth of the weight of the pod, 100 pounds of floss per acre. He estimated that under cultivated conditions the yield would be 300 pounds. Rheineck (*40*) reports proportionate yields from the pods, as shown in tables 7 and 8.

TABLE 7.—*Yields of the different parts of the pods of Asclepias syriaca collected in 1932, computed from air-dried mechanically separated material*[1]

Part of pod	Separation No.—		
	1	2	3
	Percent	*Percent*	*Percent*
Fruit walls	35.35	32.72	32.70
Seed hairs	24.45	23.20	24.40
Seeds	38.60	42.55	41.15
Placentae	1.62	1.53	1.77

[1] Data from Rheineck (*40*), published in 1939.

TABLE 8.—*Yields from 500 gm. of fresh pods of Asclepias syriaca collected in 1933, computed with reference to the fresh fruit and the air-dried fruit*[1]

Part of pod	Fresh fruit	Air-dried fruit
	Percent	*Percent*
Fruit walls	13.68	41.25
Seed hairs	7.44	22.44
Seeds	11.44	34 49
Placentae	.60	1 81

[1] Data from Rheineck (*40*), published in 1939.

HARVESTING AND PROCESSING OF THE BAST FIBER.—Meitzen (*35*) in 1862 tried two methods of processing the plant for bast fiber: dew-retting and water-retting. In dew-retting the stems were harvested at the beginning of August while the plant was still in bloom. They were dew-retted for 4 weeks, shocked, dried for 14 days, and taken in for processing. The bast was then easily separated from the wood by slightly crushing the stems. The stems were next processed as is flax. This method did not produce clean fiber, however, for the parenchyma with the latex vessels clung to the fibers, and the latex acted as a cement. It was difficult to work the fibers completely free, for the bast bundle tended to comb out to tow.

In water-retting, stems were cut in November, dried for overwintering, and in the spring were retted for 4 days in water. The stems were rolled to separate the woody parts and processed as flax. These fibers likewise were not free of parenchyma. The fiber obtained was more cottony and flexible than that obtained by dew-retting, but the yield was less. Meitzen considered water-retting more effective.

Kassner (*30*) in 1887 reported much the same problem as Meitzen: the rubber-containing tissue near the bast fibers interfered with the retting process. Kassner overcame this difficulty by extracting the latex material before retting. He passed the dried stems through rollers to break and separate the woody tissues, and removed them, leaving only the bark and bast, which contained the latex tissues and the bast fiber. He extracted the latex materials carrying the rubber by treating them with benzene or carbon disulfide. The remaining plant tissue then responded more readily to the soaking and retting.

Neish (*37*) also found that separation of the fiber presented mechanical and chemical difficulties. Neish and Burns (*38*) tried three methods of preparation, of which the most successful was retting in a tank. The period of retting which resulted in maximum strength of fiber was 9 to 10 days, with an average temperature of 65°. After 11 to

12 days the fiber was more readily separated from the wood but was weak and brittle. Retting for 14 days resulted in bacterial action which rotted the whole stalk. After retting, the stalks were passed between grooved rollers, which separated the bulk of the fiber. These investigators reported that chemical methods were unsuccessful and that the fine fibers were lost by the mechanical method of passing the green stalk through grooved rolls. The coarse fibers which remained were strong and not very brittle.

Kondratsky (*32*) reported in 1928 that if the leaves were removed when the stems were pulled, so that no downward movement of the latex occurred, the fiber was readily freed. A light boiling in a soap solution removed the adhering tissues and made the fiber glossy. Gerhardt (*20*) says that in Iowa the stems were harvested in early October. They were cut, tied into bundles, shocked, and stored for future use. After 8 days of tank-retting, the fibers were completely free from stem tissues.

There are very few reports of yield from field plantings. In Russia Kondratsky (*32*) reported a crop of 250 pood (1 pood=36.1 pounds) of stems harvested from one dessiatine (2.7 acres). The first-year yield from the experimental plot of the Iowa Experiment Station (*29*) was estimated at 1,800 (Gerhardt says 2,000) pounds of air-dried stem tissue per acre. For the second year Gerhardt (*20*) reports 2,000 pounds and in his summary calculated a maximum yield of 3,700 pounds of stem per acre. The percentage of fiber in this dried stem tissue has been variously estimated. Meitzen found 5.2 percent (*35*), Neish 9.18 (*37*), Kondratsky 17.0 (*32*), Gerhardt 10.0 (*20*), and Ulbricht 13.8 (*45*). Ulbricht believed that this percentage could be increased through breeding and proper methods of cultivation. On the basis of a 17-percent yield of fiber, dry weight, Kondratsky calculated the highest yield per dessiatine as 42.5 pood and the average yield as 20 to 30 pood.

Uses of the Floss.—The first recorded use of the floss seems to have been for upholstery or stuffing material, in 1746 by Gleditsch (Kuz'menko, *33*). Lichtenstein (*34*) found it too lumpy for this purpose. Dodge (*15*), on the other hand, found this its only use. More recently, Neish (*37*) and Neish and Burns (*38*) have also explored this possibility. They found the floss light, resilient, and water resistant. It was readily shaken up and did not become lumpy. Gerhardt (*20*) reported that its brittleness resulted in broken fibers and dust but that in articles covered with a close-woven fabric its lightness, fluffiness, and resiliency serve well. He noted also that the floss is well adapted for use in automobile upholstery because it does not absorb moisture. Berkman also considered that its resistance to moisture made it suitable for use in bedding in wet climates (*2*); in addition, its high cellulose content would make it verminproof and sanitary, and its springiness would prevent its packing. Berkman (Stouffer, *43*) thought also that the floss could be used in pillows for persons who are allergic to feathers.

The floss was early and repeatedly tried as a textile fiber. Meitzen's analysis (*35*) showed that it was structurally unsuitable for spinning, and his practical tests established its inadequacy. The floss was spun with cotton, one part floss to two, three, and four parts cotton. The spun threads were white, silky, and smooth, but with any tension or

rubbing the brittle fiber quickly disintegrated, leaving the duller cotton. Merrill (*36*) described a similar experience in his attempt to make a milkweed silk fabric. Floss gathered by hand was carded with supplementary cotton. This was spun into coarse, hard-twisted yarn; softer twists did not run well. The yarn was more lustrous than ordinary yarns but so weak that no breaking tests were attempted. It was woven into a fabric which was soft, smooth, and lustrous. But it too was weak, and rubbing loosened thousands of short bits of the fiber from the cloth. Merrill concluded that the smoothness of the hairs had allowed the numerous short lengths to slip out of the weave.

The insulating qualities of the floss were demonstrated by Neish and Burns (*38*), who used it in a sleeping bag for a test period of 3 weeks. The experiment was successful but not conclusive. Gerhardt (*20*) suggested its use in refrigerators. Berkman (*9*) testified that one value of the floss lay in its insulating qualities, and he ranked it as one of the best insulating materials in the world. He showed that it was warmer than wool and six times lighter (Stouffer, *43*). He suggested its use for lining flying suits and cited the use of kapok by the Finnish Army for its soldiers in the war of 1939 with Russia.

The use of milkweed floss as a substitute for kapok in life-saving equipment has been suggested by Neish and Burns (*38*), Gerhardt (*20*), and Berkman (*9*, *43*).[2] Berkman found that a "Mae West" life jacket filled with milkweed floss would buoy up a person in water as well as one filled with kapok (*43*). He testified that its buoyancy is greater than that of any other material except the high grades of Java kapok (*9*). A flying suit for naval aviators lined with 2½ to 3½ pounds of the floss would keep the aviator afloat for more than 100 hours, whereas other linings become waterlogged and add to the hazard. It would keep him warm not only in the air but also in the water.

According to Stouffer (*43*), Berkman has obtained a war order for this material from the United States Navy and has undertaken collection of the floss in Michigan, where there are extensive stands of the common milkweed. In Petoskey he has set up a mill to process the floss with his milkweed-ginning machine.

Neish and Burns (*38*) note that the floss does not readily deteriorate under conditions such as life-saving equipment is exposed to. They mention that the floss is extremely inflammable but add that when it is tightly packed only the surface burns.

Utilization of the floss for paper making was briefly mentioned by Meitzen (*35*) and by Neish (*37*).[3] Meitzen thought this use too expensive. He also tested the floss for possible use in guncotton but found it unsatisfactory as to both detonation and ash residue. A recent article on Russian utilization of milkweed (*51*) likewise referred to its use in guncotton, and Gaister (*18*) noted that it might be used to obtain cellulose. Berkman (Stouffer, *43*) suggested the possibility of felting the hairs into light and waterproof hats.

Uses of the Bast Fiber.—The usefulness of the bast fiber has been variously evaluated. Neish and Burns (*38*) reported that some of the coarse fiber seemed to be suitable for cordage but that its quality was readily influenced by season and soil type. Gerhardt (*20*) found that

[2] For tests of the buoyancy of milkweek floss, see pp. 6–7.
[3] The use of *Asclepias* in paper making is further discussed on pp. 29–30.

in his material the tensile strength of the fiber was too low to compete with hemp, ramie, or jute in use for cordage.

The bast fiber has been suggested for use in textiles. Gerhardt (*20*) compared it to flax and thought it might be used similarly. Neish (*37*) considered it suitable for thread material because of its silky appearance, whiteness, and strength. Kondratsky (*32*), Nerling (*39*), and Ulbricht (*45*) emphasized its ready cottonization as an advantage in spinning. Nerling identified the new English fiber "cotine" as cottonized bast fiber and said that it showed economic possibilities.

On the other hand, Meitzen (*35*), working in 1862, considered the fiber of no practical use because it was too brittle and the process of separating bast fiber clean enough for spinning was too difficult. Neish and Burns (*38*) also reported that it could not be used as a textile material.

As the bast fiber is a part of the stem, it could be used with the other parts of the stem in paper making and as a source of cellulose for rayon and for explosives. These are discussed in the last section of this review, under Other Products.

ASCLEPIAS INCARNATA (SWAMP MILKWEED)

Fischer (*17*), in his study of *Asclepias incarnata*, reported that it is a native of North America, extending from Louisiana to Saskatchewan. He particularly called attention to its northern limits: as far as 54°. Boyce, as cited by Dodge (*16*), described it as a swamp plant with stems 5 to 7 feet high, growing annually from a perennial root. Fischer found that its stems were 60 to 100 cm. high, and under cultivation as high as 120 to 170 cm. The perennial root is a thick and much-branched crown from which long roots extend. Two to five stems rise from it, each stem simple or infrequently branched in the upper portion, bearing opposite, linear lanceolate leaves and rose-to-purple, five-parted flowers in crowded umbels. The flowers are insect-pollinated, chiefly by bees. Of the two carpels in a flower, usually only one develops into a fruit, a pod containing many seeds. The seeds are flat and brown, with the characteristic tuft of silky hairs. In his examination of plants from different sources, Fischer found that the fruit varied in length and that minor differences appeared in leaf form, internodal lengths, stem length, and branching habit. All contained latex. Fischer considered the presence or absence of latex was not of consequence in fiber quality.

Characteristics of the Bast Fiber.—The literature on the fiber of *A. incarnata* seems to be concerned entirely with the bast fiber. Dodge (*15*, *16*), Neish and Burns (*38*), and Fischer (*17*) all thought it would prove more practicable than that of *A. syriaca*. Dodge (*15*) in a Department of Agriculture survey in 1894 considered it the most promising of the indigenous bast fibers of the United States. Neish and Burns found the fiber long and flexible. In one trial Neish (*37*) obtained fiber strands 3 to 6 feet in length, which he described as closely resembling flax but stronger, although not as strong as similar fibers of manila hemp. Dodge (*15*) cited a report that the strands were stronger than flax or hemp and that, as twine, they withstood a breaking test up to 95 to 125 pounds. The Imperial Institute (*26*) analyzed samples from plants grown in England and reported the cells

of the cottonized bast fiber to be highly lustrous and fairly strong. They stated that the average measurements of the fiber cells were about the same as those of cotton, although varying over a wider range. Their data are shown in table 9.

TABLE 9.—*Measurements of bast fiber cells of Asclepias incarnata grown in England* [1]

Class	Length	Diameter
	Inches	*Inches*
Maximum	2.3	0.0014
Minimum	.7	.0005
Average	1.2	.0008

[1] Data from the Imperial Institute (*26*), published in 1931.

The chemical examination reported by the Imperial Institute (*26*) showed an ash content of 0.9 percent and a moisture content of 6.2 percent, as compared with cotton, which has 0.12 to 1.7 percent ash content and 6.5 to 8.0 percent moisture. Analysis of the cellulose showed a high percentage of alpha-cellulose. The Imperial Institute compared the alpha-cellulose content of *A. incarnata* with that of cotton, as shown in the following tabulation:

	Percent of alpha-cellulose
A. incarnata sample	89.7
Cotton, American type	95.0
Cotton, Egyptian type	95.2

They noted that this is a fairly high percentage of stable alpha-cellulose, about equal to that in high-grade bleached chemical wood pulps used for the manufacture of artificial silk, but somewhat less than in cotton. Analyses of the quality of the cellulose showed it to be less durable on mercerization than cotton, since it loses 15.2 percent in the process, whereas cotton loses 5.4 percent. Tests for gain on nitration showed that the initial gain was somewhat higher for milkweed than for cotton but the nitrated material from milkweed was considerably less stable. The Imperial Institute concluded, accordingly, that the bast fiber of *A. incarnata*, although it is a possible source of fiber, would probably prove less durable than cotton.

CULTURE.—*Asclepias incarnata* can be grown successfully on dry soil, although it is a swamp plant, according to Kirkwood (*31*). Boyce carried on extensive experiments in its culture (*4*), much of his work being done in the swamps near Saginaw, Mich. He found that it grew best in these moist soils. He stated that, although the initial cost of clearing and planting swampy soils was considerable, the cost of later care of this perennial was small as compared with the cost of annual plantings of flax, hemp, and cotton. Dodge (*15*) reported that it did not grow well on upland soils and under cultivation. He stated that, if it would thrive in swampy waste land, it need not enter into competition for acreage with such established fiber crops as hemp.

Fischer, who has given the most recent (1941) and the most extensive report on the culture of this species, found that in Germany it grew in either open or lightly shaded areas and on all types of soil—clay, loam, or sand.

Propagation both by seed and by root division is described. Dodge (*16*) cites Boyce as saying that a root can be divided into pieces sufficient for 5 to 10 plant hills, and will produce stalks the same season. Fischer (*17*), however, concluded that for plantings in Germany, where the plant is not indigenous, seed is necessary. He advised the use of root material for replacement of plants in plantings already established.

Pods for seed were harvested after they had begun to yellow and dehiscence had started, because it was found that seeds collected at an earlier period germinated poorly. They were planted either in the field directly or in the greenhouse. In the field they were planted at a depth of 3 cm., 5 to 10 cm. apart, and in rows 15 to 20 cm. distant, between the middle of April and the middle of May. The seeds germinated in 8 to 14 days. For the best development of the seedling, weeding was found essential. Plants started in a greenhouse seedbed were set out in rows about the middle of May, when they were 6 to 12 cm. in height. Both these methods brought in a harvest the first year. After the establishment of the planting, Fischer reported, there is little to do in maintenance except weeding and filling in gaps in the planting with pieces from several-year-old rootstocks. Planting the milkweed in as close a stand as possible suppresses the weeds and produces tall, unbranched stems. Dodge also advised close planting. Fischer reported good results from a mineral fertilizer applied during the winter, but said that further research in this is needed. The young shoots sprout from the end of April through the beginning of May. As these sprouts are easily broken, the field should not be worked during this period. Stem growth is greatest during May and June, and the plant blooms from July to September. A single planting continues to grow for 5 to 10 years. Ball, as cited by Dodge, says it grows for 12 years. Dodge, however, considered that a new planting would be necessary oftener because in 6 years the soil would become filled with roots and inferior fiber would result.

Fischer (*17*) found milkweed in Germany to be free of pests and diseases. Kirkwood (*31*) in Canada, however, reported damage from the caterpillar of the archippus butterfly. Fischer reported an unexplained premature dying of some stems—0.2 to 0.5 percent. This did not injure the root. He also reported frost injury to the growing plant, and even to the rootstock. Drought checked stem growth, but that was counterbalanced by increased growth during the next rainy period, and all plants were of normal height at harvesting.

Fischer's observations on pollination showed that the plant was both self- and cross-fertile. He found this characteristic and the possibility of vegetative propagation useful for breeding and selection. The results of his work on this subject are not yet available.

Harvesting and Processing the Bast Fiber.—Boyce (*10*) claimed that in the Gulf States *A. incarnata* may yield two harvests each season. Both Dodge (*15*) and Fischer (*17*), however, reported a single harvest. Dodge stated that the fiber should not be harvested until it reaches maturity—that is at the end of the growing season. Fischer reported harvesting in Germany in October, when the lower leaves had turned yellow.

The processing of the plant was briefly referred to by Fischer, who stated that the stems were cut close to the soil and then handled as flax or hemp. Boyce, cited by Dodge (*15*), however, found the stems

difficult to handle by any known process. In a later publication, Boyce (*10*) claimed that he had developed a special "electro-ozone" process whereby a perfect silky fiber, "ozone" fiber, was obtained, but he did not describe it. Neish (*37*) reported that the separation of the fiber involved difficult problems. In one case where the plants had gone to seed, the fibers were freed in a single strand by a simple mechanical process, followed by carding. The fibers were free from other tissue and, when bleached with dilute sodium hypochlorite, were pure white with a silky luster. Mechanical treatment of green plants resulted in gummy fibers, but when plants cut green were retted, as is flax, for 9 days the fibers were readily separated. In later work Neish with Burns (*38*) reported procuring excellent fiber of *A. incarnata* by retting in a tank: however, their material of this species was so limited that no definite results were reached.

Reports of yield are rather meager. Kirkwood (*31*) calculated a yield of dressed fiber equal to 26 percent. Boyce (*10*) claimed a production of 500 to 700 pounds of raw fiber per acre per annum. Dodge (*15*), however, considered that positive statements as to yield could not be made until an acre or more had been regularly cultivated. More recently, in 1941, Fischer (*17*) stated that the harvest in dried stems ran from 104 to 150 dz./ha.,[4] which indicates a fiber yield of 8 to 12 dz./ha. if the fiber content is reckoned at 13 percent. The area under cultivation was not stated.

Uses of the Bast Fiber.—There are no detailed accounts of experiments on utilization of the bast fiber of *A. incarnata*. Kirkwood (*31*) stated in 1867 that this fiber had been under consideration both for paper making and for use in textiles. Dodge (*15*) reported attempts to use the fiber for twine in Minnesota in 1890. Tests made by a commercial concern with wild material indicated that it would be suitable for twine. Dodge (*15*, *16*) stated that as it resembled hemp it probably could be employed in all uses to which hemp may be applied. Boyce (*10*) asserted that the fiber had been successfully used in making tapestry yarns when mixed with waste silk (*4*, *10*) and that strong and good-looking samples had been produced when the fiber was mixed with wool—80 percent "ozone" (*Asclepias*) fiber and 20 percent wool (*24*). Neish (*37*) thought it had possibilities as a textile fiber because of its silky appearance, whiteness, and strength; and as a thread or rope material because of its length and strength. Goulding (*21*), in reviewing the work of the Imperial Institute, said that the unevenness in length of the cottonized fiber plus the lack of a natural twist might make it difficult to use in machinery designed for cotton. He concluded, however, that, if machinery could be successfully adapted, this fiber might be made into fabrics of soft and practical quality, and that it might be spun successfully if mixed with cotton.

OTHER SPECIES

In addition to the two species so far discussed there are several others which have been investigated to a limited extent. Two of these are American in origin. The first, *Asclepias tuberosa* (butterflyweed or pleurisy root) is reported by Neish and Burns (*38*) to have a bast fiber as long, flexible, silky, and strong for textile use as that of *A*

[4] Dz. (100 kg.) = 220 pounds ; ha. (hectare) = 2.47 acres.

incarnata. The second, *A. curassavica* is native in southern United States, Mexico, the West Indies, and parts of South America (*16*). Its floss was reported by both Dodge (*16*) and Wiesner (*49*) to be stronger than that of *A. syriaca*. The Imperial Institute, London (*26*), referred to its use for stuffing cushions and stated that it was unsatisfactory for spinning except when cotton is mixed with it. Three other species, investigated by the Imperial Institute (*26*), are found in Africa: *A. fruticosa*, *A. glaucophylla*, and *A. semilunata*. *A. semilunata* was studied also in Australia, where it is naturalized (*1*, *47*). Experiments with all these species are reported in the publications of the Imperial Institute (*22*, *23*, *24*, *25*), and are rather fully reviewed (*26*).

RUBBER PRODUCTION

HISTORY

The presence of rubber, caoutchouc, in the latex of an *Asclepias* was reported in 1844 by Schultz (*72*) in *A. syriaca*. Rheineck (*40*) considered this the first record. In an analysis of 80 gm. of the latex Schultz identified 5 gm. as "elastin," that is, rubber. In 1873 Lamb, according to Whalley (*81*), obtained patents for extracting rubber from milkweed. In 1875 W. Saunders (*71*) experimented with the extraction of rubber from *Asclepias*, hoping to utilize an otherwise worthless material.

Kassner in 1886 (*59*) found that the rubber content of *A. syriaca* was 6 percent. He pursued his investigations further and in 1887 gave a more detailed account (*30*). Marek (*62*) found 1.5 percent pure rubber remaining in the residue after dehydration of the latex. The presence of rubber was also determined in *A. stellifera* from South Africa, by Hillier (*58*) in 1909. Rubber was extracted from the root by maceration. The rubber of one sample was considered to be of good quality. A. T. Saunders (*70*), in 1910, extracted enough latex from *A. syriaca* to obtain about 2 gm. of rubber, but did not give estimates of proportions. He examined its qualities and suggested further experiment. A year later, Fox (*55*) examined the latex of this proposed rubber plant more critically. He concluded that the yield, 2 to 3 percent, was too small and the quality too inferior to make extraction profitable.

During and after the first World War the dependence of both Europe and the United States on external sources for rubber became significant, and a number of surveys were made of potential domestic rubber plants. Klein made a survey in 1917 of the native latex-bearing plants of Austria and found that *A. syriaca* contained the most rubber (Rheineck, *40*). In the United States, Hall and Long (*57*) describe a similar survey started in 1917 as a war emergency project sponsored by the State Council of Defense of California. While they checked many plants, their study (*57*), published in 1921, is essentially of the western species of *Asclepias*. The 10 highest yielding species are described rather fully, and 7 more are listed as having a low rubber content, ranging from 2.5 to less than 1 percent.

The yearbooks of the United States Department of Agriculture for 1923–27 (*54*, *77*, *78*, *79*, *80*) record a special appropriation for rubber investigations commencing in 1923 (*77*), authorizing a survey of po-

tential rubber-producing plants not only in the United States but also in tropical areas of North and South America. A desert milkweed, *A. subulata*, native of the Southwest, was described in the annual reports of the Chief of the Bureau of Plant Industry, United States Department of Agriculture, for 1924 and 1925 (*75*, *76*) as among the plants particularly investigated. In the Department of Agriculture Yearbook for 1925 this species was considered the best from the point of view of both culture and rubber production. In 1927 Cook (*54*) stated that the United States used 22 times as much rubber as any other country and was entirely dependent on imported supplies. He reviewed the experiments under way with our native plants, and selected *A. subulata* as the most promising. The Bureau of Plant Industry studied both this species and a second desert milkweed, *A. erosa* (*52*, *53*, *69*).

Russian interest also developed during the same period. Legros (*60*) in 1937, in a survey of Russian rubber research, showed the dependence of both the United States and Russia upon rubber imports and said that experiments toward a temperate-climate rubber plant have been carried out chiefly in these two countries. Pincus (*68*) stated that the Soviet Union, since it had no area climatically suitable for growing *Hevea*, organized 30 expeditions between 1931 and 1933 in order to search for native or imported rubber plants adaptable to its climate. Nebovidsky (*65*), reporting upon observations made during a trip in 1936 to Russian areas of rubber culture, described this research as organized on a large scale, including 35 experiment stations and 2,000 scientific workers. These had examined 1,048 species of plants, of which only 50 showed more than a 2 percent rubber content. The first success, according to Nebovidsky, was the discovery of tau-saghyz in 1930. Other plants followed, including vatochnik or *A. syriaca*. Sinyavskiĭ (*73*) writes of its culture, but Nebovidsky states that, as the plant was not well adapted and as its rubber content was low, experiments were not carried far. Gaister (*18*) records a 4- to 8-percent yield of rubber, mediocre in quality, and 12 percent resin. The relative importance of *Asclepias* in Russia in 1935 is shown by Pincus (*68*) in the following tabulation, which compares the development of seed production of five plants by the Government rubber trust:

Seed to cover:

Acres	*Plants*
4,270	Kok-saghyz (*Taraxacum kok-saghyz*).
2,770	Tau-saghyz (*Scorzonera tau-saghyz*).
1,300	Guayule (*Parthenium argentatum*).
800	Vatochnik (*Asclepias syriaca*).
320	Eukommia (*Eucommia ulmoides*).

Nebovidsky (*65*) says that investigators succeeded by chemical methods in changing the yield of *A. syriaca* from 2 percent rubber and 9 percent resin to 8 or 9 percent rubber and 2 percent resin. As Legros (*60*) suggested and as recent reports (*51*, *74*) have more fully developed, vatochnik is significant also because it has many byproducts in addition to its rubber.

ASCLEPIAS SYRIACA (COMMON MILKWEED OR SILKWEED)

Botanical Characteristics.—*Asclepias syriaca* has several characteristics which make it suitable for rubber production, as shown by

Hall and Long (*57*). It is abundant, and it is hardy, developing to a large size as far north as New Brunswick and Saskatchewan. Its growth is robust and upright, and it forms numerous and large leaves. It is able to spread rapidly by its branching underground roots so that it covers large areas and forms dense stands, a characteristic which is also important in its cultivation for fiber.

According to Hall and Long, the rubber in *Asclepias* is carried in the latex, as is true of *Hevea* but not of guayule, where it occurs in the cells of the plant. Any part of the milkweed which contains an abundance of laticiferous tissue is a rubber-bearing part. In *A. syriaca* the leaves are the most productive, while the amount of rubber in the steam is negligible. Rheineck (*40*) found a small amount also in the wall of the pod—1.19 percent; Berkman (*9*) stated that this yield is 5 percent. Leisle (*61*), from observations made in field experiments, found rubber accumulation in the leaves and not in the stem or root.

Rubber Content.—Figures previously cited [5] indicate wide variation in the rubber content. Kassner (*30*) was perhaps the first to analyze the factors causing this variation. He noted that the amount of material extracted varied according to the part of the plant and the age of the plant. The leaves often gave 7 percent, but the woody stems only 2 percent. Leaves and stems collected in May gave 2.47 percent. in August 5.5 percent, and in September 7.2 percent. (These percentages show total extract, not rubber alone.) In a test for rubber in dried leaves, he found 0.15 percent in May, 1.13 percent in August, and 1.61 percent in September.

Hall and Long (*57*) thought that the variation was dependent upon three factors: time of collection, strain of the plant, and environment. According to their analyses, the yield was least in the stem, approximately 0.3 percent, higher in the leaves, and highest in mature leaves. They also found considerable differences among plants: a robust plant tends to contain a higher percentage than a smaller one. In the leaves the yield varied as follows:

	Percent
Young leaves	0.53 and 1.4
Older leaves, lower stem	1.10 and 2.4
Green leaves	2.1, 3.6, and 4.2
Yellowing leaves	4.1 and 4.4

Gerhardt (*56*) also studied the differences in rubber content in the plant. The root showed no rubber, the stems only traces. Thus the leaves are the organ of rubber synthesis and storage. He also noted the gradual increase with maturity. His figures of the percentage of rubber in leaves and stems during the growth cycle, on an air-dry basis, are as follows:

	Rubber (benzene extract)
Date of collection	*Percent*
May 15	0.49
June 5	.60
June 23	.81
August 5	1.50
September 7	2.55
October 6	2.85
November 10 (after frost)	.82

[5] See pp. 18–19.

Further data on the effect of frost showed a loss of more than four-fifths of the rubber after a killing frost:

	Percent of rubber
Before frost	2.53
5 days after frost	1.54
2 weeks after frost	.50

Novikov and Gerber (*66*) observed that rubber formation is more energetic under the direct rays of the sun, and decreases abruptly, or even ceases, on misty or cloudy days. This suggested that rubber formation is induced by sunlight, particularly by the ultraviolet portion. They experimented with leaves of *A. syriaca* previously saturated by centrifugal force with a 3-percent sugar solution and irradiated for 1 hour and 30 minutes at 80 cm. from the source of light. The results are shown in table 10.

TABLE 10.—*The effect of ultraviolet irradiation on the rubber content of untreated and treated leaves of Asclepias syriaca* [1]

Solution	Irradiation	Rubber content of dry substance				
		Immediately	After 1 day	2 days	3 days	4 days
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Water	−	1.63	1.99	0	0.15	
	+	1.98	.66	.30	0	
Sugar, 3 percent	−	1.79	1.20	.40	.15	
	+	1.60	2.11	2.41	4.50	4.09

[1] Data from Novikov and Gerber (*66*), published in 1933.

The leaves which had been saturated with sugar and irradiated continued rubber synthesis in the dark, increasing their content 2.8 times in 3 days. They concluded, accordingly, that ultraviolet rays induce rubber formation, and that an after-effect follows irradiation. Plants of tau-saghyz grown from irradiated seeds showed, when harvested in the fall, an increase in rubber content of almost 3 times that of the controls. They considered the implications of this of immense practical value. The experiment was not reported for milkweed. Leisle (*61*) also, as the result of observations in field experiments, concluded that rubber formation occurs in the presence of light and is connected with the assimilation of carbon dioxide.

ANALYSIS AND EXTRACTION.—The methods of analysis and of extraction of the rubber of *Asclepias* have had little treatment in the literature. Whalley (*81*), in a recent review of extraction of rubber from plants with low rubber content, cites two early American patents by Lamb (1873), in which extraction from *Asclepias* is described. The plant material, which had been dried as is hay, was cut fine, boiled or steamed to disintegrate the fiber, pressed to expel the water, and then allowed to ferment for 3 days. It was treated with a suitable solvent and distilled, leaving the gum or rubber as a residue. Apparently Lamb found this of poor quality, as he advocated the addition of other rubber to make it more elastic.

W. Saunders (*71*) in 1875 investigated the value of fermentation during the processing of the plant. The whole plant was collected, cut coarse, and allowed to ferment in heaps for several days. The

mass of material was dried and ground and given several successive treatments with the solvent, carbon disulfide. It was then distilled to produce the rubber residue. In the control material, the process of fermentation was omitted. The yield of rubber was greater from the fermented material, as shown in table 11, and, in addition, the author considered the rubber of better quality.

TABLE 11.—*Yield of rubber from unfermented and fermented material of Asclepias syriaca* [1]

Yield from solvent (carbon disulfide)	Unfermented lots		Fermented lots	
	Lot A	Lot B	Lot A	Lot B
	Grains	*Grains*	*Grains*	*Grains*
First half pint	55	50	193	148
Second half pint	27	30	110	71
Third half pint	33	18	39	40

[1] Data from W. Saunders (*71*), published in 1875.

The next record of extraction is that of Kassner (*30*) in 1887. Rheineck (*40*) refers to this as the first recorded experiment worthy of notice in which the rubber was separated from the other ingredients of the milky juice. Kassner treated the dried plant material with benzene or carbon disulfide. This gave a brown solution which in turn gave a viscous oily residue after evaporation. This residue, according to Kassner, was composed of nearly 50 percent plant wax, 20 to 25 percent pure rubber, and 25 to 30 percent chlorophyll and other pigments. When it was boiled with alcohol and caustic lye, the wax and some of the other substances were separated off, and the rubber remained with only slight impurities.

Hall and Long stated that they followed methods of analysis generally used by rubber chemists (*57*). The plants were cut at the base or the approximate level where a low-set mowing machine would cut. The ends were plunged into dust to prevent loss of latex. The cut plants were then dried in an oven for 12 to 24 hours at 40° to 50° C. Higher temperatures were likely to result in the conversion of the caoutchouc into resins or other oxidation products. For further processing, the leaves were separated from the stems so that they could be analyzed separately and the location of the rubber determined. The material was ground fine enough to pass through a 30-mesh sieve, with a small amount of more coarsely ground pieces to make the mass more workable. The extraction was made in a Bailey-Walker apparatus, with a slight modification in filling it. The first extraction used boiling acetone on a water bath for a 3-hour period, which was found adequate for the removal of the acetone-soluble chlorophyll, fats, resins, and similar substances. As rubber is also slightly soluble in acetone in the presence of fats, some trace of rubber might have been present in this extract residue, but the authors considered it negligible. After distillation the remaining acetone was removed by drying. A second 3-hour extraction used boiling benzene on an electric plate. The final residue, when the solvent had been distilled off, was considered by Hall and Long to be crude rubber, though probably not a pure hydrocarbon. This whole procedure was carried out on a scale of 5 gm. of the material treated with 10 cc. of each solvent.

More recently, in 1939, Rheineck (*40*) in his phytochemical study of the plant obtained the rubber by extraction with petroleum ether. About 1,900 gm. of powdered oven-dried material was placed in small Soxhlet extractors and treated continuously for 1 week with "Skelly solvent" (boiling point 65° C.). The extract, about 100 gm., was then dissolved in chloroform and treated with alcohol, which precipitated the crude rubber. After several precipitations, Rheineck considered the product to be pure rubber.

PROPERTIES OF THE RUBBER.—A. T. Saunders (*70*), without analyzing the latex, coagulated by gentle heating a sufficient amount to obtain about 2 gm. of rubber. He did not examine this material until more than 10 years later, when he found that the gum was about 20 percent hydrocarbon, although it contained much vegetable matter and resin. Fox (*55*) described the latex as thin, acid or neutral in reaction, not coagulating on standing in a closed vessel, imperfectly coagulated by acids and ammonia, but coagulated by heat and alcohol.

Gerhardt (*56*) made a more extensive analysis of the latex of *A. syriaca* and compared it with that of *Hevea brasiliensis*, or Para rubber, as shown in table 12.

TABLE 12.—*Percentage chemical composition of latex from milkweed and from the Para rubber tree*[1]

Constituent	Milkweed (*Asclepias syriaca*)	Para rubber (*Hevea*)
	Percentage	*Percentage*
Moisture	70.00	70.00
Ash	1.40	.26
Total sugars	4.00	.79
Resins	23.00	1.22
Rubber	3.34	27.07
Total nitrogen	.46	.24
Hemicellulose	6.52	----------
Disaccharides	0	----------
Dextrin and starch	0	----------

[1] Data from Gerhardt (*56*), published in 1929.

Milkweed, he found, contains nearly 20 times as much resin as *Hevea* contains, and only one-eighth as much rubber. He concluded that the formation of the latex in the two plants is quite different, and that milkweed is the inferior source of rubber.

Orlova (*67*) in her review of investigations in the latex of several Russian rubber plants, found that the hydrocarbon base of the rubber of *Asclepias* was the same as for Para rubber, although in further tests the *Asclepias* molecule appeared to have a different structure. Matsurevich (*63*, *64*), on the basis of his studies of the latex, concluded that the caoutchouc from *Asclepias* had the properties of the tropical rubber latexes, and that it contained a bromide, an iodide, and a nitrosate.

As to the quality of the rubber, in 1887 Kassner (*30*) characterized the product which he obtained as having all the qualities of rubber imported from the Tropics. It was resistant to acids and alkalies and capable of vulcanization, which increased its elasticity to that of imported rubber. In 1910 A. T. Saunders (*70*) extracted a gum which had some of the qualities of balata, but more of rubber. It had a specific gravity slightly higher than 1, yielded to the usual

rubber solvents, and resisted the same reagents, so far as tested. Temperature softened it as it does gutta-percha, but the milkweed rubber had more elasticity and was susceptible to cure. Treated with acid it could extend to 5 times its length, with sharp recovery. Saunders considered the rubber promising, but Fox (*55*) found it inferior. He reported that it was flabby, lacking in strength and firmness, and high in gravity. It responded to the chloride and bromine tests.

The rubber obtained by Hall and Long (*57*) from *Asclepias* species showed the elasticity, resilience, and other properties of crude commercial rubber of a low grade, but they made no thorough tests and thought that considerable variation might be expected from different species. As previously cited, Gaister (*18*) also referred to the quality as not particularly high. Orlova (*67*) found *Asclepias* rubber especially sensitive to temperature, but less so to oxidation and still less to light.

Culture and Harvest.—Little reference is made to the cultivation of *Asclepias* for commercial rubber production. Hall and Long (*57*) state that to be successful the plant will have to produce large yields on cheap land. They find no direct evidence that *A. syriaca* will grow on soils unsuited to other crops. The plant must likewise be one which can be handled entirely by machinery, for which *A. syriaca* is well adapted because of its tallness and erect growth.

The relation between the habitat and the rubber content of milkweed was brought out by Neish (*37*), who stated that the soil type had a great influence on rubber production, dry soils giving a higher yield than wet soils. Hall and Long have reported that a vigorous plant of *A. syriaca* produces as much rubber as a smaller one, or more.

The time of harvest was noted by Lamb (cited by Whalley, *81*) as preferably at the time of bloom. Kassner (*30*), Hall and Long (*57*), and Gerhardt (*56*) give data indicating a maximum content at the time of full maturity of the plant in September or October. The analyses by Gerhardt also indicate that collection of the plant before a killing frost is essential, as the reduction in rubber content is drastic following such a frost.

Concerning the yield, a handbook of Russian agriculture (Gaister, *18*) records a yield of 100 to 150 kg. of pure rubber per ha. obtained from the annual crop of two tons of leaves from plants seeded at the rate of 4 to 5 kg. per ha.

ASCLEPIAS SUBULATA (DESERT MILKWEED)

Botanical Characteristics.—*Asclepias subulata* is a desert plant which grows as far north as southern Nevada and southward to the end of Lower California and Sonora, Mexico, and from southeastern Arizona to the coastal range of California. Hall and Long (*57*) state that it is not abundant anywhere. It grows in areas ranging from dry slopes or stony places, where water is available infrequently or only for a short time, to depressions where the water supply is of longer duration.

Hall and Long describe this plant as a perennial with a deep root system and a branching crown from which the erect stems arise. These stems, which may number over 500, differ considerably in

height—from 2 to 5 feet according to Beckett and Stitt (*52*) but as much as 8 feet according to Hall and Long. In further measurements by Beckett and Stitt the stems are one-fourth to one-half inch in diameter, woody at the base, with a grayish-white bloom above. Hall and Long call the stem the photosynthetic and rubber-producing organ, as the leaves are small and persist for only a short period. The stem is the part of the plant analyzed by both Hall and Long and Beckett and Stitt.

Hall and Long considered the possibility of two races or subspecies. One is more xerophytic and more woody, with plants smaller in size, averaging 30 to 40 branches; the other is less xerophytic, and woody only at the base, with larger plants having as many as 100 to 600 stems. On the basis of limited analysis, Hall and Long reported the larger type to have a better rubber yield. Beckett and Stitt disregarded this distinction, making selections for experimental work on the basis of high rubber content in individual plants.

Rubber Content.—The rubber content as recorded by Hall and Long showed a variation of 0.8 to 6.5 percent among different plants, at different seasons, and in different environments. Beckett and Stitt also found a similar range—from 0.5 to 6.0 percent, with the greatest number of plants averaging 3.0 to 3.5 percent. These authors also analyzed the factors influencing these differences. Samplings of rubber content were correlated with growth, fruiting, and dormancy. The plants show active growth and fruiting in the spring and summer but are dormant in the fall and winter, although the periods of activity may not be the same for all plants. The results showed higher rubber content during dormancy.

Beckett and Stitt also noted that a higher portion of the rubber is found in the younger and less woody upper part of the stem than in the lower part. The figures ranged from 2.22 to 3.31 in the apical portion, and from 0.96 to 1.75 in the basal portion. The woody tissue contained only 0.10 percent of rubber, while the bark, proportionately greater in younger parts of the stem, contained 5.99 percent.

Hall and Long (*57*) implied that in many of the desert species changes from the natural habitat or changes in soil, water supply, vigor, or growth may also bring about variations in rubber content.

By means of breeding experiments, Beckett and Stitt attempted to turn to account the differences among the plants, but found the naturally cross-pollinated and self-incompatible plant difficult to work with; hence they obtained no successful results.

Analysis and Extraction.—Hall and Long used the methods previously described for *A. syriaca*. Beckett and Stitt followed the methods of Hall and Long.

Properties of the Rubber.—In the literature on *A. subulata*, little reference is made to the rubber itself. Hall and Long refer to *Asclepias* rubber in general as being of a low grade. According to a recent test (*50*), X-ray photographs of the rubber of *A. subulata* do not show the crystal structure which is characterisic of *Hevea* rubber. The conclusion was drawn that the milkweed is an entirely different type of plant and contains little or no useful rubber. The vulcanized product was likewise found to be inferior.

Culture and Harvest.—Some experimental work in the cultivation of this species has been carried out at the station at Bard, Calif.,

as described by Hall and Long (*57*) and Beckett and Stitt (*52*). Hall and Long reported unpublished work by Reed, in which propagation by transplanting and by division of the crown was successful. Beckett and Stitt reported lack of success with cuttings but no difficulties with the seed, either in germination or later transplanting. The seeds were started in tar-paper pots and the seedlings transferred to the field when 6 to 8 inches tall. Experiments in field planting indicated that close planting reduced the size and weight of the individual plants but increased the total yield per given area. For the first 2 years the fields were cultivated and irrigated in the spring and again in the summer, but after this period they were irrigated only as needed. The plants attained maximum rubber production in 4 years.

One of the characteristics of *A. subulata* noted by Hall and Long was its ability to send up new stems if the old stems are cut back. This suggested the possibility of successive crops. Beckett and Stitt made a number of tests of this trait. Plants of different ages were harvested during spring, summer, fall, or winter. Records for the rate of regrowth showed best results after January or April cuttings. The plants required as long a period to recover their maximum size and rubber content as they required to grow from seed, that is 3 or 4 years. Harvesting during a dormant period resulted in better regrowth. They expected that a new crop would be produced in 3 years and every 3 years thereafter.

For the yield of rubber, Hall and Long estimated about 300 to 500 pounds per acre. This calculation was based not on field practice but on wild plants having a 3- to 6-foot spread and a 3.1 percent rubber content. Beckett and Stitt give no estimate.

In regard to storage, Beckett and Stitt discovered that rubber content of harvested material was quickly reduced by exposure to weather but when the material was protected in a dry and darkened room the rubber remained nearly unchanged for at least 2 years.

ASCLEPIAS EROSA

Botanical Characteristics.—Beckett, Stitt, and Duncan (*53*) report that *Asclepias erosa* is also a desert species, growing in dry, gravelly stream beds and depressions of the arid regions from southern California to north-central Sonora, Mexico, and north to Utah. It also is a perennial herb. New shoots are produced early in March, show rapid spring growth, and reach maturity in the fall. The stems are upright, 3 to 6 feet high, numbering 8 to 20 per plant. The leaves are abundant and large, 6 to 8.5 inches long and 2.5 to 3.5 inches wide at the base. They are shed shortly after reaching maturity in the autumn.

Rubber Content.—Hall and Long (*57*) found in three samples a range in rubber content from 1.54 in the leaves to 0.48 in the stem. In the more extensive work of Beckett, Stitt, and Duncan the difference in production between low- and high-yielding plants was found to be very great—from 2.45 to 13.06 percent in the leaves. This was the highest rubber content recorded for any *Asclepias*, and the mean also was the highest (*53*). In addition, progeny selections from high-

yielding parents tended to continue the high rubber content. The leaves contain over 90 percent of the rubber and form 50 percent of the plant weight. The maximum rubber content is reached with maturity of the plant, and a study of one-year plants indicated that this occurs early in the life history of the perennial.

Analysis and Extraction.—The extraction of the rubber by solvents was similar to that described by Hall and Long for *A. syriaca.*

Culture and Harvest.—Beckett, Stitt, and Duncan attempted propagation by the seed, which germinated readily, though seed of late-season pods showed low viability. One lot of seed was planted in tar-paper pots and later transplanted; but seeds directly planted in the field succeeded just as well. These were cultivated for weed control and irrigated as needed.

The plants were harvested in the autumn by cutting off the entire plant a few inches above the ground. These were dried for processing. A storage test was made with the leaves, which were ground, put into a paper bag, and stored in a dry room with usual light. They showed no appreciable loss in rubber in 18 to 20 months.

OTHER SPECIES

Eight additional species were studied by Hall and Long (*57*).

Asclepias sullivanti.—This species ranges from southern Ontario and Ohio to Kansas, Nebraska, and Minnesota. It is not abundant. Its habitat—moist lowland—would place it in competition with other more profitable crops; and its adaptability for other sites is unknown. The stout, erect stems with numerous leaves could be readily harvested. The leaves, which form 50 percent of the total weight of the plant, would be the part used. Their rubber content averaged 3.7 percent, but some plants showed much higher amounts. One plant contained 8.1 percent, suggesting to Hall and Long the possibility of breeding and selection. This species gave the highest rubber yield of any they examined.

Asclepias californica.—This is found only in western California, and not abundantly. It grows on a limited supply of moisture, from which the investigators judged that cultivation would be possible on poor soil; however, its nonerect growth and woolly hairiness might make harvesting and processing difficult. The rubber content varied from 4.1 percent in leaves in good condition to 0.9 percent in very old leaves.

Asclepias latifolia (broadleaf milkweed).—*A. latifolia* is distributed from Nebraska and Colorado to Kansas, Texas, and Arizona. It grows on dry, well-drained soils and is possibly well-suited to sandy or stony slopes. It tends to spread rather than to grow erect, and probably rises from a single stout root, which would permit sturdy regrowth after cropping. Rubber content varied from 2 to 3.8 percent. Hall and Long calculated a probable yield of 281 pounds per acre of the unimproved plant.

Asclepias mexicana.—This species grows in Mexico and northward to Arizona, Nevada, California, Idaho, and Washington. It is abundant in the hot interior valleys and thrives on moderately alkaline soils. It is accordingly adapted to some of those valleys of California and Nevada now uncultivated because of dry or alkaline conditions.

Its ready regrowth after cutting indicates a possibility of two crops a year. The highest yield of rubber was 4.8 percent from the leaves. Since the leaves are few in number, the stem is also important. One plant yielded 2.3 percent from the stems and 4.4 percent from the leaves, but there was considerable variation downward from this.

Asclepias galioides (whorled milkweed).—This plant ranges from Utah and Colorado south into Mexico and Central America, and is most abundant in New Mexico and Arizona. It grows naturally in dry places and on foothills but readily becomes established on overgrazed lands and fallow fields, along irrigation ditches, and in neglected orchards. Hall and Long (*57*) and other investigators (Marsh and others, *86;* May, *88*) describe it as a vigorous grower and a pernicious weed highly poisonous to stock. Rubber content is probably similar to that of *A. mexicana*, to which it is so similar that Hall and Long suggest it may be a variety.

Asclepias brachystephana.—This milkweed is most abundant in New Mexico. It is xerophytic, growing on dry mesas and foothill slopes. Its stems are low and slender and its leaves narrow, so that its total yield would not be great. The rubber content is about equal for stems and leaves, varying from 1.7 to 3.0 percent.

Asclepias speciosa (showy milkweed).—This has the widest distribution of all the western milkweeds, occurring in Alberta, Minnesota, Iowa, Texas, Arizona, California, and British Columbia, from low interior valleys to mountain meadows. It is tolerant of a wide range of temperature, but exacting in water requirement. Its yield of rubber is low, at most only 3 percent.

Asclepias eriocarpa.—This species is found only in California. It grows on poor, stony, or dry soil, but responds to better locations by better growth. It is robust, leafy, and erect and is thus suitable in growth habit for cultivation. The rubber content, on the basis of limited sampling, varies from 2.4 percent in the leaves to 0.5 percent in the stems.

OTHER PRODUCTS

The literature on *Asclepias* has shown that primary interest has centered in fiber or rubber production. However, secondary products have also received attention (*18*, *20*, *30*, *35*, *37*, *38*, *57*, *82*). The various species have been used in medicine (*85*), as a food plant (*83*, *84*, *89*, *95*), as a honey plant (*17*, *35*, *60*, *93*), and as a source of dyes (*90*), of plant wax (*9*, *30*), of lignin (*9*) and of chlorophyll (*6*). The fact that some species are poisonous is also of significance in the utilization of the plant. Muenscher (*91*) lists the following species in the United States as poisonous, or reported to be poisonous, to stock or other animals:

A. galioides H. B. K.
A. mexicana Cav.
A. verticillata L.
A. pumila (Gray) Vail
A. eriocarpa Benth.
A. speciosa Torr.
A. fremontii Torr.
A. syriaca L.
A. tuberosa L.

The secondary uses of which studies have been made are the production of pulp for paper and insulating board, of cellulose for rayon and explosives, and of oil and seed cake from the seed.

PAPER

Meitzen (*35*) in 1862 considered the floss of *A. syriaca* suitable for paper making, as it was light and white without bleaching; however, he judged the cost of harvest prohibitive. Dodge (*16*) referred to the bast fiber of *A. syriaca* as a good paper material. Neish (*37*) experimented with the production of paper pulp, probably from *A. syriaca*. He found that the woody tissue made up 80 percent of the total weight of the plant. The first treatment—with 112 gm. of soda per liter at 120 pounds of pressure for 4 hours—was too drastic, so that the pulp was gummy. A 2-hour treatment proved adequate and after bleaching gave a true chemical pulp which produced a paper of good strength and appearance, reacted well to dyes, and showed a natural sizing.

Hall and Long (*57*) experimented with the western species, *A. subulata*. Mature stems of the plant were collected and sent to a paper mill for processing. The material was (1) cooked for 3 hours in an open kettle with 10 percent (by weight of material) of caustic soda; (2) crushed out through wringer rolls; (3) washed clean and dried (yield, 43 percent of pulp); (4) cooked for 3 hours at 30 pounds pressure in a closed kettle with 10 percent (by weight) of lime; (5) washed, beaten in a beater, and run onto hand molds to produce unbleached paper (yield, 33 percent of unbleached paper). The unbleached paper was treated with a solution holding 7 percent (by weight) of bleach powder. This process yielded 28.5 percent of bleached paper of good quality.

In a second experiment by Hall and Long, stem material was boiled in water in an open kettle for 8 hours and then cooked with 10 percent caustic soda for 8 hours at 30 pounds pressure. This stock was washed, beaten, and run into hand sheets. The yield was 40 percent, and the paper was as good as in the first experiment—soft and pliable. A third experiment was similar to the second except that the material was cooked with 10 percent lime. The yield was the highest, 42 percent, but the paper was less soft and pliable.

Hall and Long suggested further that the rubber could be extracted in such a way that the fiber could be used in paper making. This would possibly eliminate the cooking with caustic soda and the crushing and washing which follow. The paper manufacture would begin with the lime treatment.

Paper was considered among other byproducts in the experiments with *A. syriaca* at the Iowa Experiment Station (Gerhardt, *20*). Examination of the stem had shown that it was suitable for pulp. There was a high content of alpha-cellulose: 36.68 percent, which is almost equivalent to that of spruce; and only 12.56 percent of lignin. Other investigators (*40*, *41*) have found slightly more than 20 percent of lignin. The fibers showed good hydration capacity, length, tensile strength, and freedom from discoloration. Gerhardt experimented with three different methods of producing pulp. The first was mechanical. In it hydration of the fibers occurred in the beating process. The yield was 86 percent. In the second the material was cooked with 10 percent caustic soda for 8 hours at 20 pounds pressure, and the yield was 65 percent. He considered this treatment too severe.

In the third the pulp was cooked with 10 percent of lime instead of caustic soda, but the procedure was the same. The yield was 82.5 percent. The first and last experiments produced a fine-quality paperboard and newsprint, while the second, too-severe treatment, gave a dark, hard board, which warped.

Orlov (*92*) also has described Russian experiments with *A. syriaca.* Seven hundred and twenty kg. of stem material was (1) ground fine; (2) cooked with 420 kg. of Na_2SO_3, 40 kg. of Na_2CO_3, and 1.590 liters of water for 16 hours at a pressure of 5.6 to 6 atmospheres; (3) washed and dried (yield 53.8 percent); (4) treated with 3 percent HCl for 1½ hours; (5) washed for 2½ hours; (6) bleached with $CaCl_2$ for 5 hours at 30° (yield 43.2 percent); (7) bleached with 13 percent kaolin, 3 percent glue, and 4.5 percent alumina. The yield of paper obtained by this method was 291 kg.

Berkman (*9*) also experimented with paper making from the stem of *A. syriaca.* He found that 77 percent of the stem was woody tissue and unsuited for paper making, but that the bast fiber was excellent for this purpose. He testified that he had patented a method whereby these parts can be separated economically by mechanical means and flotation, and that any type of paper can be obtained from the bast either alone or mixed with other pulp.

Experiments in the manufacture of insulating board from milkweed pulp are reported by Sweeney and Arnold (*94*) from the Iowa Engineering Experiment Station. The stalks were passed twice through a rod mill and beaten for 45 minutes in a Hollander beater. The authors rated the resulting product as a very good board with a pleasing gray color, having a modulus of rupture of 390 pounds per square inch, and weighing 580 pounds per 1,000 square feet of ½-inch-thick board.

CELLULOSE

Gerhardt (*20*) emphasized the quantity and quality of the cellulose in the stems of *A. syriaca*—36.68 percent of alpha-cellulose. He considered it a good source of this material, for which the demand has increased so greatly that our supply in the future must depend on annual sources. Orlov (*92*) obtained a cellulose from the stems of *Asclepias* like the wood cellulose which is used in the manufacture of rayon. He cooked the stems with 20 percent Na_2SO_3 and 3 percent Na_2CO_3 for 4 hours at 170° to 180° at 8 atmospheres pressure. This gave a 25 percent yield, consisting of 85 percent alpha-cellulose, 0.8 percent ash, 1.4 percent products soluble in ether, and 1.6 percent products soluble in ether and alcohol. Further treatment was the same as for wood cellulose. Berkman (*9*) likewise considered the 92 percent alpha-cellulose of the bast fiber a source of cellulose for rayon.

Experiments by Meitzen (*35*) with the use of the floss for explosives and the possibility of the same use, more recently, in Russia (*51*) have been discussed above.[6] The Imperial Institute (*24*, *25*) tested the bast fiber of *A. fruticosa* and of *A. semilunata* and found that its large cellulose content and its gain in weight on nitration—nearly 50 percent—adapt it for this use. Berkman (*9*) also said in his testimony that the bast fiber of *A. syriaca* could serve for this purpose.

[6] See p 13.

OIL

The seed of *Asclepias*, which is discarded when the floss is used, is the source of an additional byproduct—oil. Neish (*37*), working in 1913 with either *A. incarnata* or *A. syriaca*, probably the latter, calculated that the seed production was about 177 seeds per pod, with a total weight of about one gm. per pod, and 10 to 20 pods per plant, or an average of 15 gm. of seed per plant. The yield per acre obtained at Iowa (*29*) in the second year was rated as 30 bushels of seed, weighing 20 to 25 pounds per bushel. Gerhardt (*30*) on the basis of the same experiments calculated a maximum yield of 48 bushels of seed per acre.

Neish (*37*) extracted with ether a yield of 21 percent of oil from finely ground, air-dried seed of *A. syriaca*. This oil showed the color and consistency of fresh linseed oil and had an iodine value of 130. Neish and Burns (*38*) found that the soil affected yield and quality of the oil, as well as of the fiber. Using both *A. syriaca* and *A. tuberosa* and extracting with petroleum ether or, to a limited extent, by press, they found that seeds from a limestone soil gave an average yield of oil of 12 percent, with an iodine number of approximately 130; sandy soil gave a 22-percent oil yield with an iodine number of 142; clay soil gave a small yield of poor quality. The best seeds gave 28 percent oil, poor seeds 8 percent. A comparison of the yield of *A. syriaca* grown in different soils is as follows:

	Percent
Limestone soil	9
Sandy soil	13
Clay soil	4

Their analysis, probably of the mixed oils, showed the presence of glycerides of linolenic, isolinolenic, oleic, and archaidic acids. Exact proportions are not given, as these varied with the quality of the sample. Similarly their tables of constants given for different samples indicate variation.

The drying qualities of the mixed oils of *A. syriaca* and *A. tuberosa* were tested by Neish and Burns (*38*). A comparison was made with linseed oil, in which 1-gm. samples of each were placed on glass slides and heated at 108° C. for various periods. The results are shown in table 13.

TABLE 13.—*Properties of linseed and milkweed oils at the end of various periods of drying*[1]

Oil	6 hours	12 hours	18 hours	24 hours
Linseed	Soft skin	Soft skin	Hard skin	Hard skin.
Milkweed	Thickened	Thickened	Hard skin, very little strength.	Hard skin, brittle.

[1] Data from Neish and Burns (*38*), published in 1921.

They also tested different driers, of which manganese resinate and lineolate and the corresponding cobalt salts were successful. From these tests they concluded that milkweed oil of itself is not a good paint oil. However, when it is blended up to 10 or 20 percent by volume with linseed oil, they found that it gives strength and elas-

ticity to the linseed oil when dry. For varnish, blended with other oils, the milkweed oil gave added strength and luster. Neish and Burns tested it for making linoleum. Treated like linseed oil for this purpose, the milkweed oil produced a linoleum which was strong but brittle.

Gerhardt (*20*) classified the oil of the common milkweed as a semi-drying oil, as is that of cottonseed, sunflower, and soybean. The oil was refined by heating to 51° C., agitating with sodium hydroxide, and filtering. When it had been washed with water to remove all traces of alkali, it was golden yellow in color. Gerhardt considered possible its use as a good grade of summer yellow oil. Bleaching with fuller's earth produced a clear and colorless oil with the appearance and consistency of a vegetable cooking oil.

Matsurevich (*87*) also classified the oil of *A. syriaca* as a semi-drying oil, consisting mainly of the glycerides of oleic acid, 35 percent; glycerides of linoleic acid, 53.5 percent; and other lesser quantities of glycerides, 7 to 11 percent, mostly of palmitic and stearic acids. It has a characteristic odor, which he attributed to the presence of special phytosterols.

Rheineck (*40*) made a more exhaustive study of the composition of the oil from *A. syriaca*. Using petroleum ether, he extracted 18.8 and 19.4 percent oil from ground, moisture-free seeds. This oil also had a characteristic odor and was brown in color. Agitation with a small quantity of fuller's earth clarified and bleached the oil to a light lemon yellow, and reduced the odor. Rheineck also determined the constants of the oil and gave a tabular comparison of his results with those of Neish and Gerhardt, as shown in table 14.

TABLE 14.—*Constants of the oil from seeds of milkweed as determined by 3 investigators* [1]

Constant	Neish	Gerhardt	Rheineck
Saponification No.	184.9	193.0	198.0
Iodine value	129.8	128.0	118.0
Index of refraction	1.4738	1.4715 [at 30° C.]	1.4711
Specific gravity	.9351 [at 15° C.]	.9230 [at 15° C.]	.908
Free acid		4.0	.8
Thiocyanate value			74.5
Hexabromide			

[1] Data from Rheineck (*40*), published in 1939.

Rheineck made a further analysis of the fatty constituents. He did not find linolenic acid, but identified linoleic acid, oleic acid, and a small quantity of saturated acids not further studied. The proportions of these fatty acids, determined from the iodine and thiocyanate values, he gave as follows:

	Percent
Saturated acids	8.63
Oleic acid	35.90
Linoleic acid	50.50
Glycerol residue	4.60

Berkman (*9*), in his studies of the oil as a byproduct from *A. syriaca*, obtained a 21-percent yield. He stated that the oil is similar to that of soybeans and can be used for the same purposes. Stepanov (*74*) and other Russian investigators (*51*) reported a 17-percent yield of

oil, which can be used as a siccative or in the production of a liquid soap for the textile industry and of hard fats by hydrogenation.

Neish and Burns (*38*), probably working with *A. syriaca* and *A. tuberosa* mixed, at first considered the seed cake which remains after the extraction of oil a possible cattle food, but chemical analysis showed a toxic glucoside belonging to the saponins and similar to that found in *A. galioides* which others (Marsh and others, *86*; May, *88*) have described as a dangerous stock-poisoning plant.

Recently emphasis has been placed on the importance of these secondary products to any effort toward making milkweed a paying crop (*7*, *9*, *43*, *51*, *60*, *92*). Berkman (*6*, *9*) investigated the potential uses of the pods, leaves, and stalks. These are outlined by Stouffer (*43*) as follows:

1. In paper making.
2. In the chemical industry, using cellulose for rayon and explosives.
3. In the textile industry, for which some of the fibers have been found to be stronger than any other fiber except jute.
4. In the wallboard and insulation industries.
5. In the plastics industry, using lignin.

Along with the production of floss, Berkman considered that the seed and pod as well might be utilized. He compared the semidrying oil and the seed cake from the seed with similar products of soybean. From the pod may be extracted 5 percent of rubber, 5 percent of wax, and a fiber suitable for paper. He considers that the rubber should be utilized under the present emergency but that the yield is not sufficient to justify its processing for that alone (*9*).

In addition to its value as a crop, Berkman (*9*) pointed out that it is a soil-holding plant. With its extensive root system—it has a downward penetration of 7 feet as well as a wide horizontal extension—and with its ability to grow in poor soil, even in a dust bowl, a planting of milkweed would not only provide a cash crop but would also serve as an important factor in preventing and in halting erosion of the soil.[7]

[7] In a paper published after the completion of this summary, Berkman outlined the progress made to March 1943 in his work on the collection and utilization of milkweed. (See footnote 9, p. 35.)

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